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Analysis of INA219 Sensor Accuracy and Precision for Current Measurement in a Wheatstone Bridge Circuit

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ABSTRACT

This study aims to analyze the accuracy and precision of the INA219 sensor for current measurement in an Arduino Uno-based Wheatstone bridge circuit. The circuit used a 100 cm nickel-chromium wire, a comparison resistor (Rb) of 100 Ω, and three unknown resistance values (Rx) of 100 Ω, 220 Ω, and 470 Ω, with a 5 V power supply. The measurement performance of the INA219 was evaluated through characterization, accuracy, and precision tests. The accuracy test using Rx2 = 220 Ω showed an average error of 0.782% and an average accuracy of 99.218%, with a maximum error of 2.564%. The precision test using Rx3 = 470 Ω at L1 = 40 cm produced an average current of 10.45 mA and a precision of 99.84%. These results indicate that the INA219 provides accurate and consistent current measurements in the tested Wheatstone bridge circuit. However, the relative measurement error increased at low current values, which should be considered when the sensor is used near the bridge balance condition.

1. INTRODUCTION

A Wheatstone bridge is a fundamental electrical measurement circuit used to determine an unknown resistance based on the ratio of resistance values in the bridge arms [1]. The measurement principle of a Wheatstone bridge is based on the balance condition, in which the potential difference between the two bridge output points approaches zero when the bridge is balanced [2]. The measurement performance of a Wheatstone bridge can be influenced by the resistance values and configuration of the bridge arms [3]. The sensitivity of a Wheatstone bridge is also an important consideration in obtaining reliable measurement results [4].

The INA219 is a bidirectional current and power monitor that measures shunt voltage and bus voltage and communicates measurement data through an I^2C interface [5]. The INA219 provides 12-bit resolution and programmable gain settings for electrical measurement applications [5]. Previous research has demonstrated the use of the INA219 for current measurement by comparing its measurement results with a calibrated multimeter [6]. The INA219 has also been applied in Arduino-based physics experiments to facilitate electrical measurements in educational environments [7]. Other studies have implemented the INA219 for electrical data acquisition and monitoring applications [8].

Previous studies on Wheatstone bridge systems have mainly focused on resistance measurement and bridge configuration [1]. Precision resistance measurement has also been investigated using adapted Wheatstone bridge techniques [9]. Other studies have investigated Wheatstone bridge sensitivity and measurement performance under different configurations [4]. Wheatstone bridge configurations have also been employed to improve the sensitivity of resistive sensing systems [10]. Recent research has further explored tandem Wheatstone bridge configurations to improve sensor sensitivity in low-pressure measurement applications [18]. Previous studies involving the INA219 have mainly focused on current measurement and validation using reference instruments [11]. The INA219 has also been applied in electrical monitoring and data acquisition systems. Calibration and validation studies have further evaluated INA219 performance using accuracy, precision, and uncertainty analysis [12]. Based on the reviewed studies, the application of the INA219 for current measurement in a Wheatstone bridge circuit using a variable-length resistive wire has received limited attention. The relationship between the sliding-contact position and the current measured by the INA219 also requires further evaluation under controlled resistance conditions. Therefore, this study focuses on evaluating the accuracy and precision of the INA219 when measuring current in a Wheatstone bridge circuit with different unknown resistance values.

Accuracy and precision are important parameters for evaluating the performance of a measurement instrument [12]. Accuracy describes the closeness of agreement between a measured value and a reference value, while precision describes the closeness of agreement among repeated measurement results obtained under specified conditions. In this study, the INA219 is integrated with an Arduino Uno as the controller and data acquisition platform. The Arduino Uno uses an ATmega328P microcontroller and operates at a 5 V operating voltage [13]. Arduino-based experimental systems have also been implemented for physics measurement applications [14]. Arduino-based systems have also been used for monitoring and control applications in instrumentation systems [15]. High-precision resistance measurement techniques have also been developed using adapted Wheatstone bridge configurations [16]. The INA219 has been applied in resistivity measurement systems for current measurement and data acquisition [17]. The performance of the INA219 has also been investigated for measuring low-level electrical quantities [18]. The Wheatstone bridge consists of a 100 cm nickel-chromium resistive wire, a comparison resistor Rb = 100 Ω, unknown resistance values of Rx1 = 100 Ω, Rx2 = 220 Ω, and Rx3 = 470 Ω, and a 5 V power supply.

The use of different unknown resistance values is intended to evaluate the current response of the INA219 at different sliding-contact positions. The measurement is performed by varying the position of the sliding contact along the resistive wire while observing the current response of the circuit. The accuracy test is performed using Rx2 = 220 Ω as a representative resistance condition, while the other resistance values are used in the characterization and precision evaluation stages. This approach allows the measurement performance of the INA219 to be evaluated under different resistance conditions without generalizing the accuracy result obtained from a single resistance value.

This study aims to analyze the accuracy and precision of the INA219 sensor for current measurement in an Arduino Uno-based Wheatstone bridge circuit. The evaluation consists of three stages, namely characterization, accuracy testing, and precision testing. Characterization is performed by observing the current response for different unknown resistance values and sliding-contact positions. Accuracy is evaluated by comparing the INA219 measurement results with a reference current. Precision is evaluated through repeated measurements under identical circuit conditions. The results are expected to provide quantitative information regarding the performance of the INA219 for current measurement in a Wheatstone bridge configuration.

2. MATERIAL AND METHODS

This study used an experimental method to evaluate the accuracy and precision of the INA219 for current measurement in a Wheatstone bridge circuit. The experimental system consists of an Arduino Uno R3 based on the ATmega328P microcontroller and operating at 5 V, an INA219 bidirectional current and power monitor with 12-bit resolution and an I²C communication interface, a 100 cm nickel-chromium resistive wire, a comparison resistor (Rb) of 100 Ω, unknown resistance values (Rx1) of 100 Ω, (Rx2) of 220 Ω, and (Rx3) of 470 Ω, and a 5 V DC power supply. The INA219 is used to measure the current flowing through the Wheatstone bridge circuit, while the Arduino Uno functions as the controller and data acquisition platform. A digital multimeter is used as the reference instrument for validating the current measurements obtained from the INA219. The measurement results are transmitted to and displayed on the Serial Monitor of the Arduino IDE.

The experimental system consists of a Wheatstone bridge circuit using a 100 cm nickel-chromium resistive wire, a comparison resistor (Rb = 100 Ω), and three unknown resistance values, namely (Rx1 = 100 Ω), (Rx2 = 220 Ω), and (Rx3 = 470 Ω). The circuit is supplied by a 5 V DC power supply. The INA219 is connected to the circuit to measure the current flowing through the bridge, while the Arduino Uno is used to acquire and process the measurement data. The measurement results are displayed through the Serial Monitor. The relationship between the main components used in the experimental system is illustrated in the system block diagram shown in Figure 1.

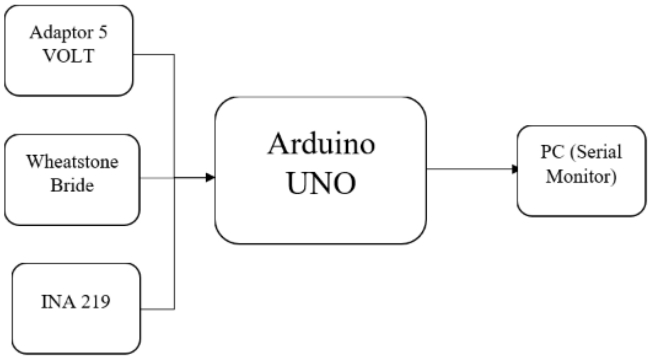

Figure 1: System Block Diagram

Figure 1 shows the relationship between the 5 V DC power supply, Wheatstone bridge circuit, INA219, Arduino Uno, and computer. The INA219 measures the current flowing through the circuit, while the Arduino Uno receives the measurement data through the I²C interface and displays the results through the Serial Monitor. The physical arrangement and interconnection of the main hardware components used in the experiment are presented in the hardware design shown in Figure 2.

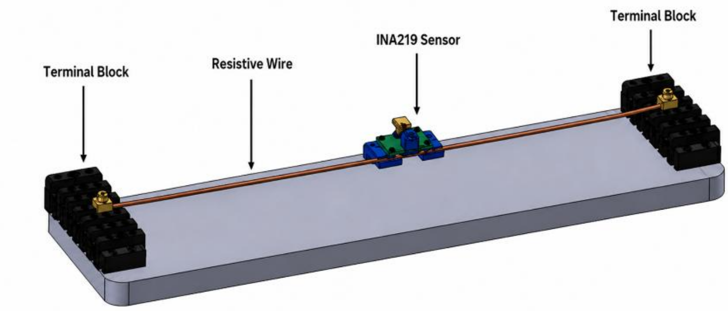

Figure 2: Hardware Design

Figure 2 shows the hardware arrangement consisting of the Wheatstone bridge circuit, INA219 current sensor, Arduino Uno, resistive wire, comparison resistor, unknown resistance, and 5 V DC power supply. The sliding contact is moved along the resistive wire to vary (L1) and (L2), thereby changing the resistance ratio of the bridge. The sequence of operations used to perform the measurement, from supplying the circuit to recording the measurement results, is presented in the system flowchart shown in Figure 3.

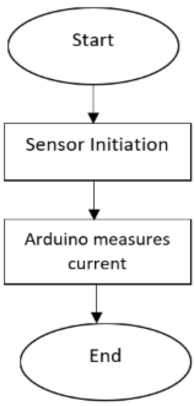

Figure 3: Flowchart

Figure 3 illustrates the experimental procedure. The process begins by supplying the Wheatstone bridge circuit with a 5 V DC voltage. The INA219 measures the current flowing through the circuit, and the Arduino Uno acquires and displays the measurement data. The sliding contact is then positioned at predetermined locations along the resistive wire. The current measured by the INA219 is recorded at each position. The measured current is subsequently compared with the reference current obtained using a digital multimeter.

The Wheatstone bridge measurement is based on the balance condition between the two sections of the resistive wire. At the balance condition, the unknown resistance is determined from the ratio of the wire lengths according to Equation (1).

$$R_x = \frac{L1}{L2} R_b \tag{1}$$

Where (Rx) is the unknown resistance (Ω), (Rb) is the comparison resistance (Ω), (L1) is the length of the wire section associated with (Rx) (cm), and (L2) is the length of the wire section associated with (Rb) (cm). The total length of the resistive wire is 100 cm, so that (L1 + L2 = 100) cm.

Accuracy testing was performed by comparing the current measured by the INA219 with the current measured using a digital multimeter as the reference instrument. The accuracy test used (Rx2= 220 Ω) as the selected resistance condition. The sliding-contact position was varied from (L1=0) cm to (L1=60) cm at 5 cm intervals. The INA219 measurement and the reference measurement were recorded for each position. The percentage error was calculated using Equation (2).

$$Accuracy\% = \left|\frac{Y_n - X_n}{Y_n}\right| \times 100\% \tag{2}$$

Precision testing was conducted to evaluate the consistency of repeated INA219 measurements under the same experimental conditions. The test used (Rx3=470 Ω) with the sliding-contact position fixed at (L1 = 40) cm. Ten consecutive current measurements were performed without changing the circuit configuration or sliding contact position. The mean current was calculated using Equation (3).

$$Precision\% = \left(1 - \frac{|X_n - \bar{X}|}{\bar{X}}\right) \times 100\% \tag{3}$$

3. RESULTS AND DISCUSSION

3.1 Characterization of INA219 Current Measurement

Characterization was performed to observe the current response of the INA219 under different unknown resistance values and sliding-contact positions. Three unknown resistance values were used, namely (Rx1=100 Ω), (Rx2=220 Ω), and (Rx3=470 Ω). The measurement results are presented in Table 1.

Table 1. Characterization results of INA219 current measurement

Rx(Ω)	L1(cm)	INA219(mA)
100	0	27.78
100	10	21.63
100	20	15.46
100	30	9.42
100	40	3.13
220	0	25.06
220	15	19.01
220	30	12.79
220	45	6.64
220	60	0.76
470	0	22.91
470	20	16.72
470	40	10.44

470	60	4.19
470	70	1.05

Based on Table 1, the current measured by the INA219 decreases as the L1 position increases for all unknown resistance values. For Rx = 100 Ω, the current decreases from 27.78 mA at L1 = 0 cm to 3.13 mA at L1 = 40 cm. For Rx = 220 Ω, the current decreases from 25.06 mA at L1 = 0 cm to 0.76 mA at L1 = 60 cm. Meanwhile, for Rx = 470 Ω, the current decreases from 22.91 mA at L1 = 0 cm to 1.05 mA at L1 = 70 cm.

The data in Table 1 are presented graphically in Figure 4 to illustrate the relationship between the sliding-contact position (L_1) and the current measured by the INA219 for the three unknown resistance values.

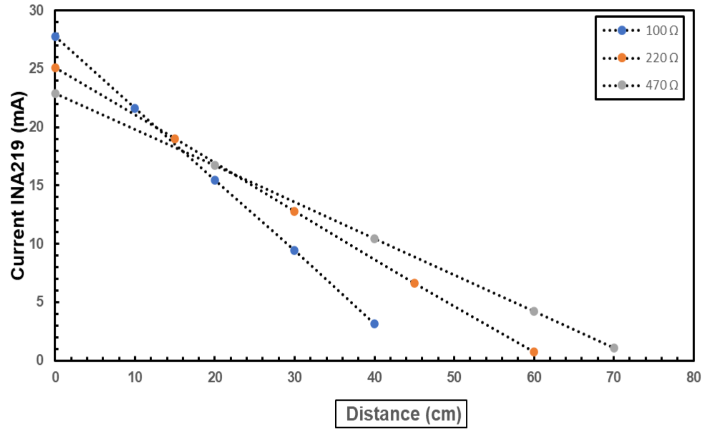

Figure 4 : Relationship between L1 Position and INA219 Current for Various Rx Values

Figure 4 shows that the INA219 current decreases as the (L1) position increases for (Rx1=100 Ω), (Rx2=220 Ω), and (Rx3=470 Ω). The decrease in current indicates that the change in sliding-contact position changes the resistance distribution between the two sections of the nickel-chromium wire. This change in resistance distribution affects the electrical condition of the Wheatstone bridge circuit and results in a change in the current measured by the INA219.

The lowest measured current in the characterization data was 0.76 mA for (Rx2=220 Ω) at (L_1=60) cm. This value represents the minimum current obtained within the tested measurement range and does not indicate that the circuit reached an exact zero-current condition or an exact bridge balance. The characterization results therefore demonstrate the response of the INA219 to changes in the sliding-contact position, while the accuracy and precision of the sensor are evaluated separately in the subsequent tests.

3.2 Accuracy of INA219 Current Measurement

The accuracy test was conducted by comparing the current measured by the INA219 with the current measured using a digital multimeter as the reference instrument. The test used (Rx2=220 Ω), with the sliding-contact position (L1) varied from 0 to 60 cm at 5 cm intervals. The selection of (Rx2=220 Ω) was used as a defined test condition for the accuracy evaluation, while (Rx1=100 Ω) and (Rx3=470 Ω) were also evaluated through the characterization test, and (Rx3=470 Ω) was additionally used in the precision test. The percentage error was used to determine the measurement accuracy, and the results are presented in Table 2.

Table 2. Accuracy Test of INA219 Current Measurement

Trial	L1(cm)	Reference Current(mA)	INA219(mA)	Error (%)	Accuracy (%)
1	0	25.74	25.58	0.622	99.378
2	5	23.66	23.53	0.549	99.451
3	10	21.57	21.45	0.556	99.444
4	15	19.52	19.41	0.564	99.436
5	20	17.39	17.29	0.575	99.425
6	25	15.31	15.22	0.588	99.412

7	30	13.14	13.07	0.533	99.467
8	35	11.01	11.05	0.450	99.550
9	40	9.04	8.98	0.664	99.336
10	45	6.91	6.87	0.579	99.421
11	50	4.82	4.78	0.830	99.170
12	55	2.76	2.73	1.087	98.913
13	60	0.78	0.76	2.564	97.436

At (L1=0) cm, the reference current was 25.74 mA, while the INA219 measured 25.58 mA, resulting in an error of 0.622%. The smallest error was 0.450% at (L1=35) cm, corresponding to an accuracy of 99.550%. The largest error was 2.564% at (L1=60) cm, corresponding to an accuracy of 97.436%. The average error was 0.782%, resulting in an average accuracy of 99.218%. The largest relative error occurred at (L_1=60) cm, where the reference current was 0.78 mA and the INA219 measured 0.76 mA. Although the absolute difference was only 0.02 mA, the difference produced a higher percentage error because the reference current was relatively low. This indicates that the relative measurement error becomes more noticeable at the lower end of the tested current range. The comparison between the reference current and the INA219 measurement is presented in Figure 5.

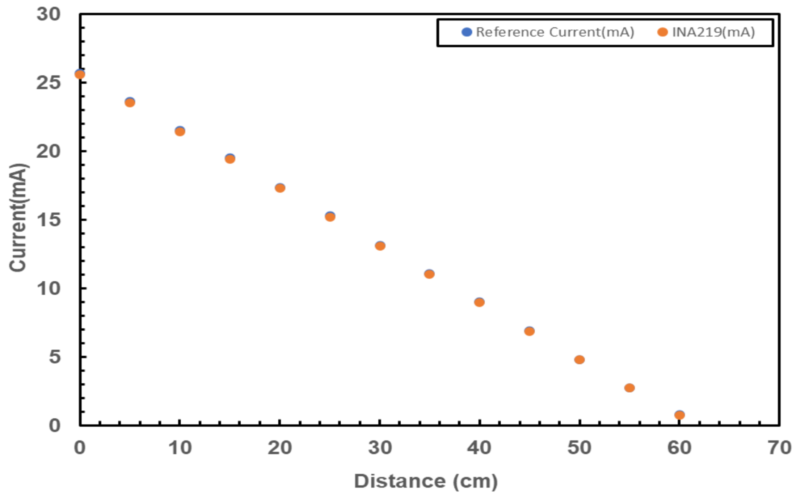

Figure 5 : Comparison of Reference Current and INA219 Current for Rx2 = 220 Ω

Figure 5 shows that the current measured by the INA219 follows the reference current across the tested (L1) positions. The difference between the two measurements remains relatively small throughout the measurement range, although the relative error increases at the lowest current level. The average accuracy of 99.218% indicates good agreement between the INA219 measurement and the reference instrument for the (Rx2=220 Ω) condition. The accuracy obtained in this study is higher than the accuracy reported in a previous INA219-based resistivity measurement system, which reported an accuracy of 97.28% for current measurement [15].

The accuracy result of 99.218% specifically represents the (Rx2=220 Ω) configuration and should not be interpreted as the accuracy of the INA219 for all unknown resistance values. The use of the other resistance values in the characterization and precision stages provides additional information regarding the sensor response but does not replace an accuracy test for those resistance conditions.

3.3 Precision of INA219 Current Measurement

The precision test was conducted to evaluate the consistency of repeated INA219 current measurements under identical experimental conditions. The test used (Rx3=470 Ω) with the sliding-contact position fixed at (L1=40) cm. Ten consecutive current measurements were performed without changing the circuit configuration or sliding-contact position.. The results are presented in Table 3.

Table 3. Precision Test of the INA219 Sensor

Trial	INA219(mA)
1	10.44
2	10.47
3	10.43
4	10.45
5	10.46
6	10.42
7	10.45
8	10.44
9	10.47
10	10.43
Average	10.45

The repeated measurements ranged from 10.42 to 10.47 mA, with an average current of 10.45 mA. The precision value was 99.84%, indicating that the INA219 produced consistent current measurements when the circuit configuration and sliding-contact position were maintained. This result is consistent with previous INA219 calibration studies that evaluated measurement precision through repeated measurements under controlled conditions [14]. The repeated INA219 measurements are presented in Figure 6.

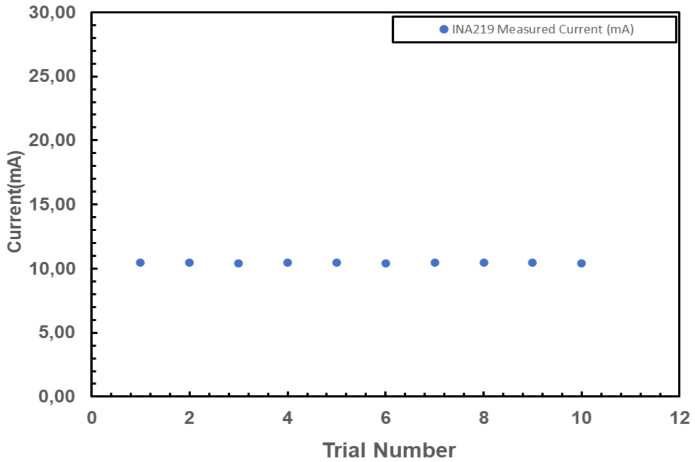

Figure 6 : Repeated INA219 Current Measurements

Figure 6 shows that the measured current values remain close to the average value of 10.45 mA, with only small variations among the ten measurements. This result indicates good repeatability of the INA219 measurement for (Rx3=470 Ω) at (L1=40) cm.

4. CONCLUSION

The results of this study show that the INA219 sensor provides a consistent current response to changes in the sliding-contact position in the Wheatstone bridge circuit for the tested unknown resistance values of (Rx1=100 Ω), (Rx2=220 Ω), and (Rx3=470 Ω). The measured current decreased as the (L1) position increased, demonstrating that the INA219 was able to detect current changes associated with variations in the resistance distribution of the circuit.

The accuracy test using (Rx2=220 Ω) showed an average error of 0.782% and an average accuracy of 99.218%, with the error ranging from 0.450% to 2.564%. The highest relative error occurred at the lowest measured current, indicating that the relative error becomes more noticeable at low current levels. The precision test using (Rx3=470 Ω) at (L1=40) cm resulted in an average current of 10.45 mA and a precision of 99.84%, indicating consistent measurements under identical experimental conditions.

Based on these results, the INA219 can be used for current measurement in the developed Wheatstone bridge experimental system. However, the accuracy result of 99.218% is limited to the (Rx2=220 Ω) condition tested in this study. Further research should evaluate accuracy using all tested unknown resistance values and a wider current range, particularly at lower current levels, to provide a more comprehensive evaluation of INA219 performance.

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